REVIEW ARTICLE

Critical Analysis of Robotic Surgery for Laryngeal Tumours

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Abstract In recent years, transoral robotic surgery (TORS) with the Da Vinci robot has been used for the removal of laryngeal cancers with the objective to improve functional and aesthetic outcomes without worsening survival. The advantages of TORS are described in this article. However, its disadvantages, mainly high cost amongst others, do not make robotic surgery the current treatment of choice for laryngeal tumours; transoral laser surgery is superior in most cases. Major technical improvements are expected. Smaller, more ergonomic, new-generation robots better adapted to the head and neck will probably be available in the near future.

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PALABRAS CLAVE
Cirugía robótica; Da Vinci; Tumores laringeos; Laringe; Revisión; Análisis económico; TORS

Análisis crítico de la cirugía robótica laringea

Recientemente se ha introducido en el bagaje quirúrgico del otorrinolaringólogo el empleo del robot Da Vinci para tratar tumores laringeos con la justificación de mejorar los resultados funcionales y estéticos sin comprometer la supervivencia. En esta revisión se describen las ventajas de la cirugía robótica transoral (TORS), aunque las desventajas de la misma, principalmente su elevado coste, nos hacen preferir otras modalidades terapéuticas, principalmente la cirugía láser transoral. Se esperan en el futuro inmediato mejoras técnicas importantes en la cirugía robótica, con aparatos más pequeños, ergonómicos, de nueva generación, mejor adaptados al área cervicofacial.

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Introduction

The Da Vinci surgical Robot was officially launched in the Hospital Virgen del Rocio in Seville on 13 September 2007, and the first operation took place on 18 September—a radical prostatectomy. Prior to that, a team comprising 3 urologists and 2 scrub nurses travelled to Strasbourg to undertake an extensive training course. The only robotic equipment for national robotic surgery training is in Granada, in the headquarters of the Fundación Iavante; it has been used to train a great many Spanish and foreign surgeons in robotic surgery techniques. The authors of this article travelled to this Foundation firstly to attend an intensive course on robotic surgery on live pigs and human cadavers and this was then completed with repeated operations on cryopreserved cadaver heads (Fig. 1). In addition to broad experience in open cervical surgery and transoral laser surgery, this team has also trained in extended endoscopic surgery of the skull base, and therefore we intended initially to cover the indications accepted in international literature on robotic surgery in otolaryngology.

Paradoxically, despite the great coverage in the media on robotic surgery, there are very few publications on the subject. In the field of ENT, robots have been used firstly in transaxillary surgery of the thyroid and by extension of the neck, where its cosmetic benefits largely justify its use as no visible scar is left; then for oropharyngeal tumours and obstructive sleep apnoea; and finally, less frequently, in laryngeal surgery. Articles are increasingly appearing on the fields of development where we consider that the robot will play a major role in the future: rhinopharyngeal and skull base surgery.

However this article is a story of frustration. In our experience, “conventional” transoral laryngeal laser surgery is so superior to robotic surgery that we have as yet had no laryngeal case for which the use of a robot has been justified. Sleep apnoea surgery is not very developed in our centre.

Oral cavity and oropharyngeal cancers are treated by the maxillofacial department, who, although also trained in the use of robots, have not requested its use. Surgery of the rhinopharynx and skull base, possible areas of development for this surgery with numerous theoretical applications for the future, in our opinion, require far more appropriate instruments than those available at present. All these aspects will be developed on in the relevant sections. It should not be forgotten that the initial idea of the robot was the idea of a surgeon operating on a patient, each in a separate operating theatre (not a separate country, but a separate planet!). The idea was not to achieve a panacea–like the laser or so many other scientific techniques and advances—superior to other conventional techniques. In fact, after the unanimity of the first publications on the advantages of the robot, articles have been continually appearing of late which question its use, indications, high cost and safety; this has meant that the enthusiasm for entering a career in robotics has dwindled.

The Da Vinci System

The term robot was coined by the Czech writer Karel Capek who used the word in his language to allude to serfs or slaves in his work of 1921 “R.U.R.” (Rossum’s Universal Robots). The Robot Institute of America’s (1079) definition of a robot is “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialised devices through various programmed functions for the performance of a variety of tasks”.

The first surgical robot was called Puma 560 and was used from 1985 to perform high precision, neurosurgical biopsies. Different devices have been developed since then, although only one has been approved by the FDA and consequently marketed in the field of cervicofacial surgery: the Da Vinci robot (Intuitive Surgical Inc.). The origins of this robot go back to the NASA project to offer surgical care to astronauts in orbit and was seen by the US Defence Department as a potential protection mechanism for the few surgeons who could operate from a remote location. The Intuitive Surgical Corporation was created in 1995 in order to develop telerobotic systems for commercial use.

Although this “astronautical” vision of robotic surgery has not become a reality, this technology has been applied in the various surgical robots, which are chiefly used in minimally invasive procedures. In our speciality, the Da Vinci system uses robotic (or roboticised) systems to enable microsurgery in various areas which are difficult to tackle using conventional endoscopic techniques. The Da Vinci surgical system is a master–slave telerobotic platform consisting of a console, a surgical trolley and a display system. The main surgeon controls the robot without entering the surgical field, at a distance from the patient, and an assistant changes and/or adjusts the different robotic arms or instruments used. The surgeon’s console provides an amplified three-dimensional image of the surgical field and allows the robotic arms to be controlled, transferring the movements of the surgeon’s hands and fingers to the robotic arms and the instruments inserted in them, and there is no physical hand tremor.

Indeed, the Da Vinci robot is used throughout the world in the area of ENT in particular, despite its high cost. The following reasons have been used to justify its use:
Robotic Surgery for Laryngeal Tumours

- Advantages of three-dimensional vision compared to the two-dimensional vision of conventional endoscopy.
- Stable vision as the camera is secured and moved by one of the robot’s arms.
- Precise, delicate control of instruments, with great freedom of movement in the 3 dimensions of space.
- Elimination of physical tremor.
- More comfortable conditions for surgeons, as they are seated ergonomically at the console.

Furthermore, public opinion has highly valued the achievement of a technological advance of this magnitude, as with the CO₂ laser, which was initially used in a great variety of ENT procedures such as surgery for snoring, whereas currently clear or well-justified indications for its use have been enormously reduced.

Critical Analysis of Relevant Literature on the Subject

After perusing the PubMed database in depth and using various search strategies, a maximum of 121 articles were found containing the words “robotic laryngeal surgery”. However, on reviewing the articles and excluding those which refer to surgery of the thyroid gland, oesophagus, mediastinum, oral cavity and oropharynx the number fell to 65. Curiously, the article by Rodrigo, Coca and Suarez on partial laryngeal surgery appears in this series! When the search was confined to the words “robotic laryngectomy”, 28 articles appeared of which 26 were valid, whereas using “Da Vinci laryngeal surgery” brought up 38 of which only 18 were useful.

In general it should be highlighted that the articles recovered are very uniform in content, as these key words bring up descriptions of new instruments, series of patients with diseases of different areas, and even review articles on a subject which is so recent.

The first articles on the applicability of the Da Vinci robot for laryngeal surgery appeared in 2005, with studies on mannequins, a canine model and a cadaver, although there had been a publication 2 years earlier which demonstrated its applicability for ENT in a porcine model, monitoring surgical times in various cervical procedures such as thyromyectomy, sub-maxilloctomy or cervical emptying. This publication recorded that it took an average of 12 min to assemble the robot, which we consider incredible. The following year, the first article appeared dealing specifically with the vocal cords, which are very difficult to access, also in a canine model. The term transoral robotic surgery (TORS) originated in this article.

The first time the robot was used on a patient was also in 2005, in the excision of a vallecular cyst. The patient underwent otorhachal intubation, a bivalve laryngoscope was used and, for reasons of space, only one robotic arm could be introduced with the monopolar electrocautery terminal, the whole procedure took 1 h and 49 min. This article exposed one of the shortcomings of the Da Vinci system in ENT, the lack of a suction system which means an assistant—not a robot—has to introduce suction, for smoke, blood and detritus.

Following on from these pioneering publications, in 2006 the group from the University of Pennsylvania, lead by Professor Weinstein, published the first work on their experience in 3 patients with tumours of the base of the tongue, followed in 2007 by the first on robotic supraglottic laryngectomy in 3 cases, with an average 120 min of surgery (between one case of an hour and a half and another of 3 h) and 18 min preparation of the team.

Probably taking laser transoral surgery for these tumours as the technique of choice, in 2007 Solares and Strome, of the Cleveland Clinic, published the use of the Da Vinci robot associated with a CO₂ laser handled through a hollow tube, and the next year the group from Mount Sinai in New York published the use of a flexible tube.

Unfortunately this initiative was not well broadcast; subsequently the works of Remacle et al., and Blanco et al. appeared on the same subject.

In subsequent years more, numerous series started to appear on patients treated with the Da Vinci system: the group from the Mount Sinai Hospital in New York published their experience on 20 patients with diverse ENT tumours in 2009, recording a mean preparation time of 54.6 min, which seems more in line with general experience.

In that year, the first review article appeared under the provocative title “TORS, does the end justify the means?”. Although the conclusions were predictable as these authors were pioneers in developing TORS in North America, controversial areas were raised in this article such as the few long-term oncological results and the problem of financial cost, on the basis of which extensive use of the robot was recommended to fully justify its price.

In particular now, and for the reasons we will discuss extensively in the relevant section, pure laryngeal cases are always in the minority in the more numerous series. For example, in the article by Boudreaux et al. of 36 patients had a laryngeal carcinoma—surprisingly, chemoradiotheraphy had failed for 5 of them—in the Essen group there were 3 supraglottic tumours in 17 cases, and in Blanco et al.’s article on their experience in 44 cases with cervico-facial area tumours, only 2 patients had laryngeal disease! In a very recent series on supraglottic tumours in Istanbul all the cases were T1, and in another series of the University of Montpellier, they were only able to recruit 23 cases in 4 years, 13 glottic and 10 supraglottic, the majority were T1.

Critical Analysis of the Da Vinci System in Laryngology

As highlighted earlier, the following can be argued with regard to the supposed advantages of the Da Vinci system over conventional surgery:

- Previous considerations: the size of the robotic system requires space and additional personnel for it to be set up for each operation, positioning it correctly, covering it with sterile sleeves, preparing the necessary material, etc. The anaesthetist is faced with new challenges as well, both in the position of the patient and the type of anaesthetic to be used.
- Display: the console does indeed provide the surgeon with a 3D display system. However, this technological advance is not itself inherent to the robot. Modern endoscopy...
techniques are increasingly incorporating 3D display systems, for sinonasal endoscopic surgery or robotic surgery (Fig. 2) alike. It is quite probable that in the immediate future all endoscopy systems will have the 3D option.

It is argued that vision is stable as the camera is secured and moved by one of the robot’s arms. This argument is irrelevant for any surgeon who performs laryngeal microsurgery using a microscope. Even endoscopy systems using endoscopy systems via laryngoscope allow the optics to be secured and therefore the image is stable. Therefore this argument does not apply when compared with transoral laser surgery.

Secondly, the robot was designed originally for abdominal surgery, where the surgical field, expanded with air, does not pose major problems in viewing the different structures. This is not the case with the upper aero-digestive tract, where the different mucous folds hinder the robotic arms and require an assistant’s hand to separate them, as well as a hand to control suction. In other words, other items need to be included in a narrow surgical field such as a suction system, or in the case of the Feyh-Kastenbauer oral retractor or similar systems for opening the mouth or moving the tongue, without forgetting the anaesthesia tube, which reduces the surgical field still further. In a series which covered the experience of 7 major centres with 130 consecutive patients, it was acknowledged that exposure was “suboptimal” (does this not just mean poor?) in 26% of cases. In another even larger series, attempts were made to treat 192 using TORS but adequate exposure was achieved for only 179; in two further cases it was not possible to complete the procedure reverting to a conventional technique.

In this multicentre series, laryngeal cases represented 14.7%, 13 out of 126 in the case of supraglottic carcinomas in a different series, which gives an idea of the difficulty in recruitment or the inclusion bias. As some publications acknowledge, “the resection of supraglottic tumours can be challenging, due to the arrangement of the robotic-arms and the narrow anatomic conditions.”

Thirdly, it is not easy to position the robot and if, in addition, not all patients are likely to present appropriate exposure using conventional direct laryngoscopy, in the case of robotic surgery, there are even fewer favourable cases. Changes in cervical spine mobility are rarely mentioned as a limitation for use of the robot. In published series inaccessible tumours are usually presented as exclusion criteria for TORS, and subsequently statements have been made such as “In all cases, tumour resection could be performed by robotic surgery exclusively…” Error! Undefined marker! (first the difficult cases were excluded and then subsequently, having operated on all of them with the robot is presented as a success!).

One field of development for robotic surgery is the design and fine-tuning of various systems for set and exposure many of which are based on other previous models. Some recent publications cover the subject of exposure exclusively.

Furthermore, it usually requires a tracheotomy to approach the vocal cords using a robot, which is regularly avoided with conventional laser surgery. Even in various series on supraglottic carcinomas most underwent a tracheotomy. There is no physical space in the area of the glottis to be able to place the anaesthetic tube, robotic arms and the viewing system together. Exclusive series on glottic cancer have been published recently where tracheotomy was avoided in the majority of cases, whereas in transoral laser surgery this is exceptional. Curiously there are articles which cite the reduction in the number of tracheotomies as an advantage of robotic surgery, which could be true for oral or pharyngeal surgery, but of course not for laryngeal surgery.

Instrumentation: the precise and delicate control of instruments, with great freedom of movement in the 3 dimensions of space, is indeed exclusively attributable to the Da Vinci system. However, at the moment, the exclusive use of monopolar electro-coagulation, compared to the use of laser in transoral surgery and the tissues managed not being touched and thus changes in consistency not being distinguished are limitations of the system. Although there are descriptions of robotic laser surgery these appear anecdotal at present. Another of the Da Vinci system’s shortcomings in ENT is the lack of an incorporated suction system, which makes it necessary for an assistant—not a robot—to introduce and handle suction of smoke, blood or detritus, in a very limited surgical field. Finally, the traction provided by the standard instrument (Maryland) of 8 mm, although it is very superior to that provided by the one designed for our speciality of a lesser diameter (5 mm), in our opinion is insufficient when the epiglottis requires traction in the case of a supraglottic laryngectomy.

Eliminating physical tremor does not seem relevant in our speciality. In transoral surgery the instruments can be supported on the laryngoscope, and the surgeon’s arms rest on the armrests of the surgeon’s chair or even on a Mayo tray, and in any case, we have not encountered, in our experience, literature or any relevant experience which justifies the use of the robot for this reason. Furthermore, the rigidity of the robotic arms of the Da Vinci system is being overcome by the development of new, flexible robotic systems.

Safety and efficiency: in general it is accepted that a surgeon has to perform from 150 to 250 robotic procedures a year in order to become expert in its use. Initial studies which compare blood loss, length of hospital stay or general rate of complications with the results of open surgery are certainly (as is to be expected) favourable to the robot. It is surprising (or not) how the great majority of comparative
studies are performed with retrospective studies of open surgery and not with patients who have undergone transoral laser surgery.\textsuperscript{33,34} In one study the comparison was even made with patients treated with chemoradiation.\textsuperscript{16} It is an obvious fact, highlighted in critical reviews of the subject, that comparisons with regard to the area of the larynx should be made with laser surgery and not with open surgery.

Cases of heat damage to the cervical skin have been published\textsuperscript{35}; this phenomenon has not been observed with laryngeal microsurgery using microelectrodes, which uses electro-dissection exclusively.\textsuperscript{36} A peak in the rate of complications of robotic surgery has been published recently, which has lead to the FDA questioning the experience of the surgeons responsible.\textsuperscript{37} The description of these incidents is quite illustrative: “In some cases, surgeons who operated robotic arms and the various tools attached to them punctured bladders, severed nerves and blood vessels, and otherwise appeared responsible for the mishaps. In other cases, the Da Vinci surgical robot seemed to have a life of its own, at times inexplicably cauterising a fallopian tube, damaging heart tissue, or refusing to let go of a patient’s tissue with its grasper. We had to do a total system shutdown to get the grasper to open its jaws, stated one report, noting that the patient was not injured.” In reality, perhaps this is less of a peak and more a true record of complications, as the use of the robot becomes more widespread, although the numbers do appear concerning: \textsuperscript{211 ‘‘adverse events’’ in 2011, 282 in 2012, and 62 in the first quarter of 2013, which seems to be leading to an intermediate number between those occurring in the 2 previous years.

Concerning the best conditions of comfort for the surgeon, sitting at the console ergonomically, we must cite Jorge Roquette in one of his brilliant presentations on transoral laser surgery comparing the surgeon to a one-man orchestra who uses his hands to operate and a foot to press the laser pedal. If this brilliant metaphor is valid, what would it be like with robotic surgery (Fig. 3), where the surgeon uses both hands for the robotic arms, his forehead as a safety system for securing the robot and both feet for electrosurgery and as the mechanisms for zooming and setting vision, respectively?

Cost: the initial price of a Da Vinci robot was in excess of a million dollars, to which had to be added more than 100,000 dollars a year as maintenance costs, and around 200 dollars per case and each disposable instrument.\textsuperscript{38} Around 2008, Intuitive Surgical Inc., the company responsible for the Da Vinci robot had installed 1032 throughout the world, of which 766 were in North America. Data by 31 March 2013 showed that there were 1957 machines, three times as many over 5 years. From 200 there are 400 in the rest of the world. Currently a cost of between 1 and 2.3 million dollars is accepted depending on the configuration and the local market.

As with any company’s expenditure, depreciation is reduced the more a machine is used, which meant that hospitals which had purchased robots used it on as many patients as possible. Some\textsuperscript{39} eventually considered the price of the robot superfluous justified by the fact that as it had been purchased for specialities with a larger volume of cases (cardiac, urology surgery) its rare use in ENT would only represent an additional saving.

Comparative studies of costs based on the length of hospital stay or duration of surgery are usually made with series on whom open surgery has been performed.\textsuperscript{15}

- Preparation of the robot: the times recorded to prepare the robot prior to the surgery itself are very variable (Table 1). The time spent preparing the robot can be used for other operations, a laser cordectomy, for example. The time published varies between 17 min\textsuperscript{40,41} and almost 1 h,\textsuperscript{15} with a mean of around 25 min.\textsuperscript{40,41}

Moreover, the instruments used are of limited use, as the manufacturing company only allow a maximum of 5 re-sterilisations; a cost of around 2000 dollars is accepted for instruments, even though only 3 instruments are used.

At present, along with the articles which show an increase in the rate of complications with the robot, which have already been mentioned, doubts are being voiced as to the value of robotic surgery in general. In this regard, a work published in JAMA in February 2013 highlighted that robotic hysterectomy presented complication rates similar to conventional laparoscopy, with an extra cost of 2200 dollars per procedure.\textsuperscript{42} Three years ago, a review of the subject was published in the New England Journal of Medicine.\textsuperscript{43} The conclusions are worth quoting:

“Evidence from well-designed, large-scale, multicenter trials or comparably rigorous nonrandomized evaluations is needed to determine which patients benefit from open surgical approaches and which from robot-assisted approaches. Hospitals could use this information in response to pressure from technophile surgeons; surgeons could use it in discussing treatment options with patients; patients could use it to make treatment choices; and payers could use it in negotiating reimbursements. An efficient health care system must enhance the ability of medical professionals and their patients to make informed choices about the adoption and use of new technologies, even when insurers do not explicitly provide reimbursement for these new technologies”.

Future Laryngeal Developments

In light of some of the difficulties encountered with the Da Vinci system, especially concerning the rigidity of the robotic arms, other devices have been developed in an attempt to overcome these limitations. The Pittsburgh group recently published studies on cadavers of a new flexible system enabling access to the upper aerodigestive tract even without laryngeal suspension.\textsuperscript{51} In May of this year another study by the same group appeared, emphasising the advantages of the system in terms of vision, facilitation of access and triangulation of instruments in the endolarynx.\textsuperscript{44}

Probably the most promising field of development for TORS in the larynx is that of total laryngectomy. At present, most laryngectomies, at least in our centre, are rescue surgery, where it is not uncommon to plan and develop flaps for reconstructive purposes. The idea of extracting the larynx through the mouth, making use of the visualisation and possibilities offered by the Da Vinci robot was suggested to us during our instruction course in lavanda, Granada, by Dr Fernández-Nogueras, who teaches robotic surgery; this is the line of research on which he is working, and which we
embraced with enthusiasm and even requested a research project.

The first article on the subject appeared in 2012, a joint article between surgeons from the University of Lovaina and the UCLA, on how to perform a laryngectomy using the robot. No patients are described, or the model used, and no surgical photographs are published, only drawings. Only in the Discussion section is it mentioned that this technique was used for both oncological and functional indications, but results are not specified or complications recorded. In general, this article could be criticised as an idea which has not been demonstrated or documented even on a cadaver, despite it being indicated that it was performed on patients.

The second article appeared this year, 2013, from 2 different centres in Ontario and New York, with the first 3 patients operated. Total robotic laryngectomy was justified with a view to minimising complications, as the majority of the patients had been rescued from chemo- and radiotherapy, and it was decided to perform a total laryngectomy in a narrow field on the 3 cases. The 3 patients spent more than 4 hours in surgery, which in our experience is more than twice the usual time for a total laryngectomy, and discharge was earlier for all the patients than after conventional open surgery. Certainly, if it is confirmed that there were no complications as described, total robotic laryngectomy is a major field for the future of cervicofacial oncological surgery.

Conclusions

Despite the very promising results published, TORS remains a surgical option which requires significant surgical skill, contrasted criteria in clinical indication and solid oncological principles, and should be chosen according to the needs of each individual patient, and for the convenience of the surgeon in charge. In the more numerous series published, it is acknowledged that as experience is gained the selection and management of potential patients improves. Clinical trials should definitely be developed comparing robotic surgery to transoral laser laryngeal surgery which at present in our opinion has advantages in terms of speed, exposure and cost, and even versatility and scope of indications.

Conflict of Interests

The authors have no conflict of interests to declare.

References


Table 1  Time Required for Preparing the Robot, Excluding the Surgical Time sensu stricto, in Different Published Series.

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Mean time (range) in minutes</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Park et al.</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>2009</td>
<td>Genden et al.</td>
<td>54.6</td>
<td>20</td>
</tr>
<tr>
<td>2007</td>
<td>Weinstein et al.</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>2011</td>
<td>Lawson et al.</td>
<td>24 (10–60)</td>
<td>24</td>
</tr>
<tr>
<td>2012</td>
<td>Vergez et al.</td>
<td>52 (±46)</td>
<td>130</td>
</tr>
<tr>
<td>2012</td>
<td>Remacle et al.</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>2012</td>
<td>Hans et al.</td>
<td>25 (15–100)</td>
<td>23</td>
</tr>
<tr>
<td>2013</td>
<td>Blanco et al.</td>
<td>17.12 (10–40)</td>
<td>44</td>
</tr>
</tbody>
</table>

Figure 3  Console of the Da Vinci robot, where the control systems for both of the surgeon’s feet, hands and the forehead can be seen.
36. Lowes R. FDA investigates robotic surgery system after adverse event spike. In: Medscape Medical News; 2013 [Apr 30].
